OFFICE OF UTILITY TECHNOLOGIES

	FY 1995
Office of Utility Technologies - Grand Total	$33,740,000
Office of Solar Energy Conversion	$15,200,000
Photovoltaic Energy Technology Division	$15,200,000
Materials Preparation, Synthesis, Deposition, Growth or Forming	$11,600,000
Amorphous Silicon for Solar Cells	3,500,000
Polycrystalline Thin Film Materials for Solar Cells	7,500,000
Deposition of III-V Semiconductors for High-Efficiency Solar Cells	600,000
Materials Properties, Behavior, Characterization or Testing	$ 1,800,000
Materials and Device Characterization	1,800,000
Device or Component Fabrication, Behavior or Testing	$ 1,800,000
High-Efficiency Crystal Silicon Solar Cells	1,800,000
Office of Renewable Energy Conversion	$ 540,000
Geothermal Division (GD)	$ 540,000
Materials Preparation, Synthesis, Deposition, Growth or Forming	$ 90,000
Thermally Conductive Composites for Heat Exchangers	90,000
Materials Properties, Behavior, Characterization or Testing	$ 450,000
Advanced High Temperature Geothermal Well Cements	300,000
Corrosion Mitigation in Highly Acidic Steam Condensates	100,000
Advanced Coating Materials	50,000
Office of Energy Management	$18,000,000
Advanced Utility Concepts Division	$18,000,000
Superconductivity Systems Program	$18,000,000
Device or Component Fabrication, Behavior or Testing	$18,000,000
Wire Technology Project	4,000,000
Systems Technology	6,000,000
Superconductivity Partnership Initiative	8,000,000

OFFICE OF UTILITY TECHNOLOGIES

OFFICE OF SOLAR ENERGY CONVERSION

PHOTOVOLTAIC ENERGY TECHNOLOGY DIVISION

The National Photovoltaics program sponsors high-risk, potentially high-payoff research and development in photovoltaic energy technology that will result in a technology base from which private enterprise can choose options for further development and competitive application in U.S. electrical markets. The objective of materials research is to overcome the technical barriers currently limiting the efficiency and cost of photovoltaic cells. Theoretical conversion efficiency of photovoltaic cells is limited by the portion of the solar spectrum to which the cell's semiconductor material can respond, and by the extent to which these materials can convert each photon to electricity. The practical efficiency is constrained by the amount of light captured by the cell, the cell's uniformity, and a variety of loss mechanisms for the photo-generated carriers. Cost is affected by the expense and amount of materials required, the complexity of processes for fabricating the appropriate materials, and the complexity and efficiency of converting these materials into cells.

MATERIALS PREPARATION, SYNTHESIS, DEPOSITION, GROWTH OR FORMING

129. **AMORPHOUS SILICON FOR SOLAR CELLS**
$3,500,000
DOE Contact: Richard King, (202) 586-1693
NREL Contact: Bolko von Roedern, (303) 384-6480

This project performs applied research upon the deposition of amorphous silicon alloys to improve solar cell properties. Efficient solar energy conversion is hindered by improper impurities or undesired structure in the deposited films and the level of uniformity of the films over large (1000 cm^2) areas. The films are deposited by plasma enhanced chemical vapor deposition (glow discharge), thermal chemical vapor deposition and sputtering. The long term goal of this effort is to develop the technology for 12 percent efficient solar cells with an area of about 1000 cm^2. Achieving that goal should enable amorphous silicon to be a cost-effective electrical generator.

Keywords: Amorphous Materials, Coatings and Films, Semiconductors, Chemical Vapor Deposition, Sputtering and Solar Cells

130. **POLYCRYSTALLINE THIN FILM MATERIALS FOR SOLAR CELLS**
$7,500,000
DOE Contact: Richard King, (202) 586-1693
NREL Contact: Kenneth Zweibel, (303) 384-6441

This project performs applied research upon the deposition of $CuInSe_2$ and CdTe thin films for solar cells. Research centers upon improving solar cell conversion efficiency by depositing more nearly stoichiometric films, by controlling interlayer diffusion and lattice matching in heterojunction structures and by controlling the uniformity of deposition over large (1000 cm^2) areas. The films are deposited by chemical and physical vapor deposition, electrodeposition and sputtering. The long term goal for this effort is to develop the technology for 15 percent efficient solar cells with areas of about 1000 cm^2. Achieving this goal would enable polycrystalline thin film material to be a cost-effective electrical generator.

Keywords: Coatings and Films, Semiconductors, Chemical Vapor Deposition, Physical Vapor Deposition, Electrodeposition, Sputtering and Solar Cells

131. **DEPOSITION OF III-V SEMICONDUCTORS FOR HIGH-EFFICIENCY SOLAR CELLS**
$600,000
DOE Contact: Richard King, (202) 586-1693
NREL Contact: John Benner, (303) 384-6496

This project performs applied research upon deposition of III-V semiconductors for high efficiency solar cells, both thin film for flat plate applications and multilayer cells for concentrator applications. Research centers upon depositing layers precisely controlled in terms of composition, thickness and uniformity and studying the interfaces between the layers. The materials are deposited by chemical vapor deposition, liquid phase epitaxial growth and molecular beam epitaxial growth. The long term goal of this area is to develop 35 percent efficient concentrator cells and 24 percent 100 cm^2 one-sun cells for flat plate applications. Achieving these goals would enable systems using these technologies to be cost-effective electrical generators.

Keywords: Semiconductors, Chemical Vapor Deposition, Solar Cells

MATERIALS PROPERTIES, BEHAVIOR, CHARACTERIZATION OR TESTING

132. **MATERIALS AND DEVICE CHARACTERIZATION**
$1,800,000
DOE Contact: Richard King, (202) 586-1693
NREL Contact: Larry Kazmerski, (303) 384-6600

This project measures and characterizes materials and device properties. The project performs surface and interface analysis, electro-optical characterization and cell performance and material evaluation to study critical material/cell parameters such as impurities, layer mismatch and other defects that limit performance and lifetime. Techniques that are used include deep level transient spectroscopy, electron beam induced current, secondary ion mass spectroscopy, scanning electron microscopy and scanning transmission electron microscopy.

Keywords: Semiconductors, Nondestructive Evaluation, Surface Characterization, Microstructure and Solar Cells

DEVICE OR COMPONENT FABRICATION, BEHAVIOR OR TESTING

133. **HIGH-EFFICIENCY CRYSTAL SILICON SOLAR CELLS**
$1,800,000
DOE Contact: Richard King, (202) 586-1693
NREL Contact: John Benner, (303) 384-6496

This project performs applied research upon crystal silicon devices to improve solar-to-electric conversion efficiency. The project employs new coatings and/or dopants and other treatments to reduce electron-hole recombination at cell surfaces or in the bulk material. Control of point defects in crystalline silicon is being studied by a variety of techniques.

Keywords: Semiconductors, Solar Cells, Crystal Silicon

OFFICE OF RENEWABLE ENERGY CONVERSION

GEOTHERMAL DIVISION (GD)

The primary goal of the geothermal materials program is to ensure that the private sector development of geothermal energy resources is not constrained by the availability of technologically and economically viable materials of construction. This requires the performance of long-term high risk GD-sponsored materials research and development.

MATERIALS PREPARATION, SYNTHESIS, DEPOSITION, GROWTH OR FORMING

134. **THERMALLY CONDUCTIVE COMPOSITES FOR HEAT EXCHANGERS**
$90,000
DOE Contact: R. LaSala, (202) 586-4198
BNL Contact: L. E. Kukacka, (516) 282-3065

This project is investigating thin thermally conductive polymer-based composites for use as corrosion and scale-resistant liner materials on carbon steel tubing used in shell and tube heat exchangers in binary geothermal processes or for bottoming cycles in multi-stage flash plants. Corrosion and scaling on the brine side of carbon steel tubing in shell and tube heat exchangers have been major problems in the operation of geothermal processes. Compared to the cost of high alloy steels, a considerable economic benefit could result from the utilization of a proven corrosion resistant polymer concrete material if sufficient heat transfer and anti-fouling properties can be derived. The work consists of determinations of the effects of compositional and processing variables on the thermal and fouling properties of the composite, and measurements of the physical and mechanical properties after exposure to hot brine in the laboratory and in plant operations. The effects of anti-oxidant additives on the fouling coefficient and scale adherence are also being evaluated. Results to date from field tests performed in FY 1994 and FY 1995 with flowing hypersaline brine under heat exchange conditions indicate heat transfer coefficients similar to those for high alloy stainless steels. The liner provided excellent corrosion protection to the carbon steel substrate, and no deterioration or disbondment of it were apparent. Improvements in the fouling coefficients by the inclusion of anti-oxidants are anticipated.

Keywords: Composites, Polymers, Corrosion, Heat Transfer, Scale-Resistant, Fabrication Technology, Fouling Coefficient

MATERIALS PROPERTIES, BEHAVIOR, CHARACTERIZATION OR TESTING

135. **ADVANCED HIGH TEMPERATURE GEOTHERMAL WELL CEMENTS**
$300,000
DOE Contact: R. LaSala, (202) 586-4198
BNL Contact: L. E. Kukacka, (516) 282-3065

Lightweight (<1.2 g/cc), environmentally benign, chemically and thermally resistant well cements are needed to reduce the potential for lost circulation problems during well

completion operations and to insure long-term well integrity. Materials designed for temperatures >400°C will be needed as higher temperature resources are developed. Cements resistant to brines containing high concentrations of CO_2 at temperatures >150°C are also needed. Emphasis is being placed on high temperature rheology, phase chemistry, and the mechanical, physical, and chemical resistance properties of the cured materials. Retarding admixtures required to maintain pumpability during placement operations are also being identified. To date, phosphate bonded calcium aluminate cement formulations containing hollow aluminosilicate microspheres appear to meet the design criteria and preparations for large-scale mixing and field placement are underway.

Keywords: Cements, Material Degradation, Strength, Phase Transformation, Bulk Characterization, Drilling, Carbonation, Retarders, Well Completions

136. **CORROSION MITIGATION IN HIGHLY ACIDIC STEAM CONDENSATES**
$100,000
DOE Contact: R. LaSala, (202) 586-4198
BNL Contact: L. E. Kukacka, (526) 282-3065

Increased HCl gas concentrations in the steam produced from geothermal wells at The Geysers in Northern California have resulted in severe corrosion problems in casings in the upper regions of wells where condensation may occur, in the well-head, transmission piping and cooling towers, and on turbine blades. The objective of the program is to optimize and field test polymers and polymer matrix composites for utilization as corrosion resistive liners on carbon steel and aluminum components exposed to low pH steam condensates at temperatures up to ~200°C. Emphasis is being placed on polymer and composite composition, metal surface modification, installation procedures and techniques for joining lined pipe sections.

Keywords: Polymers, Polymer Matrix Composites, Acid, Durability, Fabrication Techniques, Field Tests

137. **ADVANCED COATING MATERIALS**
$50,000
DOE Contact: R. LaSala, (202) 586-4198
BNL Contact: L. E. Kukacka, (516) 282-3065

Corrosion of plant components is a problem that is encountered in most geothermal processes, and low cost solutions are needed in order to maintain the economic competitiveness of this large and environmentally benign energy source. The objective of this task is to optimize and field test polymers and polymer matrix composites, developed in other parts of the Geothermal Materials Development Program, as corrosion protective systems in hypersaline geothermal processes. Successful evaluations and subsequent technology transfer will result in reduced plant construction and operation costs, increased generation efficiencies and utilization factors, and enhanced environmental acceptance.

Keywords: Polymers, Polymer Matrix Composites, Placement Techniques, Field Tests

OFFICE OF ENERGY MANAGEMENT

ADVANCED UTILITY CONCEPTS DIVISION

The Advanced Utility Concepts Division supports research and development of advanced energy storage and electrochemical conversion systems that will facilitate the substitution of renewable energy sources for fossil fuels-measures that will increase the reliability and efficiency of the energy economy. The goal is to provide reliable, inexpensive devices to mitigate the temporal and spatial mismatches between energy supply and energy demand. The research is divided into four subprograms: Superconductivity Systems, Utility Battery Storage, Thermal Storage, and Hydrogen Energy.

SUPERCONDUCTIVITY SYSTEMS PROGRAM

DEVICE OR COMPONENT FABRICATION, BEHAVIOR OR TESTING

138. **WIRE TECHNOLOGY PROJECT**
$4,000,000
DOE Contact: Jim Daley, (202) 586-1165
Argonne National Laboratory: U. Balachandran, (708) 252-4250
Brookhaven National Laboratory: David Welch, (516) 282-3517
Los Alamos National Laboratory: Dean Peterson, (505) 665-3030
National Renewable Energy Laboratory: Richard Blaugher, (303) 384-6518
Oak Ridge National Laboratory: Robert Hawsey, (615) 574-8057
Sandia National Laboratory: Peter Roth, (505) 845-9301
American Superconductor Contact: G. N. Riley, (508) 836-4200
Intermagnetics General Contact: Paradeep Haldar, (518) 782-1122

The wire technology goal is improvement in short wire samples (1 cm to 10 cm) through: improved powder synthesis, improved fundamental understanding of critical currents in high temperature superconductors, and

investigation of new wire processing methods. Improvement in long wire length uniformity is included in the Systems Technology project below.

The wire development project is the key to eventual commercialization of superconductivity systems. Subtasks in the project are as follows:

a. Green state texturing of superconductors - To increase the J_c of BSCCO superconductors by a coated-wire-in tube (CWIT) method. In this approach, fine silver (Ag) wires are coated with BSCCO-2223 superconductor powder loaded into an Ag tube and processed by the powder-in-tube (PIT) method.

b. High temperature superconductor (HTS) current leads for superconducting storage devices - The goal of this project is to develop prototype HTS leads that will be used commercially in the storage device. Developed initial specifications for a pair of vapor-cooled HTS current leads based on the requirements of superconducting storage device.

c. Thallium based HTS coils - This project has produced Tl-1223 multifilament tapes exhibiting $J_c(77K) = 10{,}000\ A/cm^2$ in short lengths, which only decreases by a factor of 4 in magnetic fields above 8T. This J_c value is superior to analogous values for BSCCO tapes at 77K and high magnetic fields.

d. Fabrication and testing of HTS wires and coils - The purpose of this project is development of necessary conductor and provision of a pre-prototype demonstration that HTS can be substituted for the NbTi winding presently used in the ORNL quadruple motor. The proposed work will augment work already in place.

e. Development of high current density superconducting wires - The objective of this project is to develop and demonstrate the technology necessary for high critical current density, oxide powder-in-tube wires using the Tl-1223 and Tl-1212 composition. Tasks to involve preparation of aerosol-derived powders, fabrication of superconducting wires, deformation processing experiments, and statistical studies to optimize the texture, phase formation, and overall superconducting properties of the wires.

f. Study of magnetic flux motion and pining in HTS - Understanding of the vortex configuration and dynamics in HTS for applied fields that are not parallel to any of the principal axes is still insufficient. As a complementary study to those related to the alignment effects by columnar defects, the response of unirradiated HTS to inclined fields will be investigated. Completed initial characterization of energetic, Tl-1223 wires.

g. Aerosol powder synthesis - The objective of this agreement is to transfer the process of forming superconducting powder precursors via the aerosol pyrolysis technique. Refined the aerosol pyrolysis technique to control Pb-BSCCO powder particle size and phase assemblage. Evaluated the effects of chemical doping of the precursor materials prior to or during the atomization process on flux pinning.

Keywords: Superconductor, Coated-Wire-in-Tube Method, Thallium, Fabrication, Current Density, Magnetic Flux, Aerosol Powder

139. **SYSTEMS TECHNOLOGY**
$6,000,000
DOE Contact: Jim Daley, (202) 586-1165
Argonne National Laboratory: U. Balachandran, (708) 252-4250
Brookhaven National Laboratory: David Welch, (516) 282-3517
Los Alamos National Laboratory: Dean Peterson, (505) 665-3030
National Renewable Energy Laboratory: Richard Blaugher, (303) 384-6518
Oak Ridge National Laboratory: Robert Hawsey, (615) 574-8057
Sandia National Laboratory: Thomas Bickel, (505) 845-9301
American Superconductor Contact: G. N. Riley, (508) 836-4200
Intermagnetics General Corp. Contact: Paradeep Haldar, (518) 782-1122
General Electric Research & Development Contact: J. E. Tkaczyk, (518) 387-5004
Oxford Instruments, Inc. Contact: K. R. Marken, (908) 541-1300

Systems technology goals include: improved uniformity in long (10 meter to 1000 meter) HTS wires, development of high field (2-5 telsa) coils, and design of high efficiency electric power devices.

The electric power application project includes development of long length wire, wire manufacture, and coil manufacture. Some preliminary systems development is also done. Project subtasks are as follows:

a. Bearing and Flywheels - The purpose of the HTS bearing scale-up project is to establish the technology base for improved flywheel energy storage systems through efficiency enhancements made possible by incorporation of HTS magnetic bearings. A critical issue is to demonstrate that low-

loss HTS bearings can be scaled up to sizes of interest for flywheel energy storage applications. The project is a continuation of the effort started in calendar year 1994.

b. Processing of Bi 2223 superconducting tape for power application - Studies of approaches to optimize phase behavior and mechanical properties in order to achieve high critical current densities in longer lengths up to 1 meter are the focus of the agreement. Active exchanges of precursor powders and silver clad tapes for further processing and characterization as well as experimental results have been an important part of this agreement.

c. BSCCO HTS working group - The objective of this project is to develop the technology necessary for commercialization of oxide powder-in-tube conductors for electric power applications. Tasking included oxide powder development using aerosol pyrolysis to develop HTS aerosol spray pyrolysis powder process and system technology for use in PIT wires.

d. Thallium-based deposited conductor development - The objective of this project is to determine the sequence of events leading to formation of textured Tl-1223 with colony microstructure during vapor phase thallination of spray-pyrolyzed deposits. Completed to reproduce on buffeted metallic and other flexible metallic substrate the high critical current property with field and temperature dependence of that obtained on polycrystalline yttria-stabilized zirconia (YSZ) substrates.

e. Development of thallium-oxide superconducting materials for electric power - Performed the collaborative studies in the two-zone thallium oxide vapor reactor processing of precursor films deposited by low-cost methods to produce Tl-based HTS conductors.

Keywords: Thallium Conductor, Composite Conductors, Long Length Wire, Bearing, Flywheels, Superconducting Tape

140. **SUPERCONDUCTIVITY PARTNERSHIP INITIATIVE**
$8,000,000
DOE Contact: Jim Daley, (202) 586-1165
General Electric Co. Contact: Kenneth Lay, (518) 387-6147
Lockheed Martin Contact: Eddie Leung, (619) 974-1166
Reliance Electric Company Contact: Rich Schiferl, (216) 266-6253
Electric Power Research Institute Contact: Don Von Dollen, (415) 855-2679

The Superconductivity Partnership Initiative (SPI) is an industry-led venture between the Department of Energy and four industrial consortia intended to accelerate the use of high temperature superconductivity in energy applications. Each SPI team includes a vertical integration of non-competing companies that represent the entire spectrum of the R&D cycle. That is, the teams include the ultimate user of the technology-the electric utilities-as well as a major manufacturing company and a small company supplier of superconducting components. Each team also includes one or more national laboratories who perform specific tasks defined by the team. The SPI goal is to design cost-effective HTS systems for electricity generation, delivery and use. The funding amount below includes the Department's share of the SPI design activities as well as parallel HTS technology development that directly supports the SPI teams. In FY 95, projects are underway for a superconducting 100 MVA generator (General Electric), fault-current limiter (General Dynamics), and 100 HP motor (Reliance, Electric Company). In addition, a transmission cable project, led by the Electric Power Research Institute and Pirelli Cable, was funded in FY 1995. All of these projects will incorporate high-temperature superconducting wire. Four Department of Energy National Laboratories are currently directly supporting the Superconductivity Partnership Projects: Argonne, Los Alamos, Oak Ridge, and Sandia. Project subtasks are as follows:

a. Generator - Results of the generator project included generator assessment activities such as defining the applications, establishing a conceptual generator design, developing a preliminary generator design and initiating the performance analysis of the generator in the utility system. In addition, wire and coil development activities will be started and include wire development, fabrication, and coil design and development. Generators represent a large established worldwide market with growth projections forecasting that over 1000GW of new generation capacity will be needed in the next 10 years, with 173 GW needed in the U.S.

b. Fault-Current Limiter - The fault-current limiter project undertook conceptual studies of various device designs, namely, to provide a market survey for current limiter applications, complete an energy benefit assessment, conduct a network interface assessment, determine conductor requirements, and analyze the economic potential of fault-current limiters. Fault-current limiters can be used on transmission and distribution systems to improve system flexibility, reliability and performance.

c. Motor - Electrical and mechanical design and thermal analysis completed. In addition, the construction of the components for a motor prototype will be nearly completed, with assembly and testing. Superconducting motors can have a large impact on electrical energy utilization through reduced losses and size compared to conventional iron core motors. The reduced losses and smaller size will be the driving forces for the commercial introduction of superconducting motors in industrial applications.

d. High Temperature Superconducting Power Cable - The first phase of the contract calls for the development and fabrication of a 30-meter prototype 115KV HTS underground power transmission cable which will be tested at a utility test site. Additionally, the project will conclude with design of a 3-phase, 100 meter cable system.

Keywords: Generator, Motor, Fault-Current Limiter, Transmission Cable